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COMPLETE SPECIFICATION

Electric Transformers and the Like

I, SHIRO SASAKI, a national of Japan, of 35, Nakasugiyama-tori, Sendai, Japan, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to electric transformers and particularly to transformers having superior frequency characteristics over a wide frequency range when used in electrical communications. It is well known that the essential factors limiting the useful frequency range of a transformer are its distributed capacitance and its leakage inductance. To reduce the distributed capacitance of a transformer having a given number of windings, it is necessary to increase the distance between adjacent conductors or between adjacent windings; this, however, results in looser coupling of the windings and a higher leakage inductance therebetween. Accordingly these two factors are contradictory.

According to the present invention, a high impedance transformer having a low leakage inductance and less affected by the distributed capacitance over a wide frequency range can be manufactured.

From the results of various experimental investigations, I have found that losses in transformers are not only related to the distributed capacitance as has commonly been considered, but are also appreciably related to the phase relationship of the voltages relatively induced between the windings by changes of voltages and currents in such forms as alternating currents, pulses or transient phenomenon of a direct current.

The principle underlying the present invention will be explained with reference to Fig. 1 of the accompanying drawings, which shows two simple transformers each comprising two solenoid winding elements. (A) shows a transformer having a primary winding W_1 and a secondary winding W_2, both windings being wound in the same direction (for example from left to right) and also wound in the same sense of winding (for example in a clockwise direction). This type of winding is referred to hereinafter as "regular interposition". On the contrary (B) shows a transformer having a primary winding W_1 and a secondary winding W_2, both the windings being wound in opposite directions and in opposite senses. The latter type of winding is hereinafter referred to as "irregular or reverse interposition".

Considering the reverse interposition as shown in Fig. 1 (B), assuming that a voltage is impressed across the terminals t_1 and t'_1 and that a current flows from t_1 to t'_1. In this case, the current reaches any point *a* before it reaches another point *b* more remote from t_1. As a result, the phase of the current at the point *a* leads that of the current at the point *b*. *a'* and *b'* of the secondary winding W_2 are points adjacent to the points *a* and *b* respectively of the primary winding W_1. The current at the point *a* of the primary winding W_1 induces a voltage at the point *a'* of the secondary winding W_2, whilst the current at the point *b* of W_1 similarly induces a voltage at the point *b'* of W_2. The induced voltage at *a'* is advanced in phase with respect to the induced voltage at *b'*. The directions of the impressed and induced currents are shown by the arrows in Fig. 1 (B). Accordingly, the induced current is directed to the secondary winding terminal t_2 and the induced current at the point *a—a'* reaches t_2 with a phase lag (transmission time) corresponding to "t_1 to *a* to *a'* to t_2" where the origin is taken to be the time at which the current enters the circuit at the terminal t_1.

Similarly, the induced current at the point *b—b'* has a phase lag corresponding to "t_1 to *b* to *b'* to t_2". It will now be apparent that the total current at t_2 is formed by the superposition of all currents from the in-phase current travelling from "t_1 to t_2" and having no phase lag, to the current travelling from "t_1 to t'_1 to t'_2 to t_2" which has the largest phase

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lag. Under these conditions, if the incoming current at t_1 is pulsating, the pulses of current arriving at t_2 will be seriously deformed and distorted.

With the regular interposition shown at Fig. 1 (A), however, the induced current in the secondary winding W_2 is directed from t_2 to t'_2 as shown by the arrow. Considering the time at which the current enters the circuit through the terminal t_1 as the origin, the current induced at *a*—*a'* reaches t'_2 after a transmission time corresponding to "t_1 to *a* to *a'* to t'_2" and the current induced at *b*—*b'* reaches t'_2 after a transmission time corresponding to "t_1 to *b* to *b'* to t'_2". As all these transmission times are equal, all the induced currents in the secondary winding reach t'_2 in phase. As a result, there is no deformation or distortion of current pulses fed through the transformer.

Thus, it will be seen that the winding construction shown in Fig. 1 (A) has a smaller effective capacitance than the winding construction shown in Fig. 1(B). Further it is known that deformation of current pulse wave forms results in a decrease of the transmission frequency band width.

This voltage phase difference between adjacent points of the windings has an important bearing on the high frequency characteristics of the transformer. The difference under operating conditions between the effective capacitance and the distributed capacitance is defined hereinafter as the "phase capacitance".

Experiments have shown that the frequency characteristic of a transformer depends not only upon the distributed capacitance between the coils but also to a large degree upon this phase capacitance.

By taking this phase capacitance into account, the dynamic and high frequency characteristics of a transformer can be determined more accurately and a transformer having uniform characteristics over a wide frequency band can be constructed.

The foregoing description is an explanation of phase capacitance in connection with two simple winding elements. The above described principle is equally applicable to more complicated transformers made by combining a plurality of winding elements.

Accordingly, the present invention comprises an electric transformer characterised in that the primary and secondary sides each have at least two single layer winding elements, all said single layer winding elements being disposed to provide alternate primary and secondary winding elements which are electromagnetically coupled and which are in intimate spatial relationship with each other, all said winding elements being wound in the same sense and in the same advance direction and all said winding elements having substantially the same dimension between their extreme terminations; said transformer having a minimum phase capacitance as hereinbefore defined between its windings.

A transformer according to the present invention having a ratio of 1 : n can be made either by using different diameter conductors for the primary and the secondary windings so that, although the windings have the desired turns ratio, the dimensions of the winding elements between their extreme terminations are equal; or the secondary windings can be so interconnected as to obtain the desired transformer ratio, this interconnection always being made in such a manner that the phase capacitance of the transformer is a minimum.

It is an object of the present invention to provide a transformer having minimum phase capacitance and a low leakage inductance between its primary and secondary windings.

Another object of the invention is to provide a transformer which is compact and which has a superior frequency response characteristic owing to its high impedance over a comparatively wide frequency range.

A further object of the invention is to provide a transformer having a large turns ratio with a low resistance loss, close coupling and high impedance over a wide range of frequencies.

Other objects, features and advantages of this invention will be apparent from the following detailed description of the principle and of the particular embodiments of the invention taken together with the accompanying drawings, in which:

Fig. 1 is a diagram showing two simple transformers each comprising two solenoid winding elements as previously described;

Fig. 2 is a diagrammatic plan view of a type of winding element utilized in a transformer according to the invention;

Fig. 3 is a connection diagram for a group of winding elements, by way of example;

Fig. 4 is a connection diagram of a transformer which is made by connecting six winding groups of the type shown in Fig. 3;

Fig. 5 is a plan view of the transformer shown in Fig. 4, one part of the casing being removed;

Fig. 6 is a sectional side view of the transformer shown in Figs. 4 and 5;

Fig. 7 shows a number of curves illustrating the frequency characteristics of several transformers according to the invention; and

Figs. 8 and 9 are diagrams of solenoid type transformers according to the invention.

A single layer winding element of the type diagrammatically shown at *a* in Fig. 2 is made by winding an insulated conductor in the form of a flat spiral or of a volute from the centre terminal t_0 to the outer terminal t'_0, the adjacent turns thereof being closely disposed to one another. For example, a winding element of this type of 5.2 centimetres outer diameter is made by winding 75 turns of 0.16 millimetre diameter wire, the element having the same thickness as the wire. A transformer can be constructed by closely coupling at least four of these elements, the elements being interconnected as hereinafter described and the resulting sets of elements being used as the primary and secondary windings of the transformer.

The natural input frequency of this transformer was measured by passing a variable frequency alternating current through the primary winding.

A transformer was constructed using four of the single layer winding elements shown in Fig. 2 closely adjacent to each other, the first and third elements being interconnected to form the primary winding and the second and fourth elements being interconnected to form the secondary winding. These interconnections were made in such a way that the sense of winding of the primary elements was the same as the sense of winding of the secondary elements. This transformer showed frequency characteristics significantly superior to those shown by a transformer with the primary and secondary winding elements wound in the opposite sense. The distributed capacitance of the transformer will be the same in each case, but the induced current in the secondary winding in the former case will be in the opposite direction to that in the latter case. The phase capacitance between the primary and secondary sides is substantially a minimum in the former case, while it is substantially a maximum in the latter case. Accordingly, it will be apparent that by minimizing the phase capacitance, the frequency characteristic of a transformer according to the present invention is greatly improved as compared to an ordinary transformer which has heretofore been manufactured without taking into account the effects of phase capacitance.

According to the present invention, the primary and secondary windings must be interposed closely adjacent to each other and must be wound in the same sense and in the same advance direction and such a disposition is hereinafter termed "regular interposition".

The above explanation has been given with reference to a winding element as illustrated in Fig. 2 but the same remarks apply equally to a solenoid type winding element in accordance with the present invention and as hereinafter described.

In accordance with the invention, at least two primary and at least two secondary single layer winding elements are used, the primary and secondary elements being alternately and closely disposed in regular interposition to provide a tight electro-magnetic coupling therebetween. In one embodiment, a plurality of winding elements are used and all the primary elements are connected in parallel and all the secondary elements are likewise connected in parallel.

According to the present invention, the transformer of Fig. 3 is constituted of four single layer winding elements which are closely coupled and which have their turns wound in the same direction and is useful as a transformer independently of the embodiment of Fig. 4.

The transformer of Fig. 3 can be used as a unit, that is, any desired number of these units can be suitably combined and connected so as to make another transformer having desired characteristics. For convenience sake a unit, such as that illustrated in Fig. 3 which has four single layer winding elements, will be referred to hereinafter as a "transer".

Fig. 3 shows the connection of a transer having four winding elements of the type shown in Fig. 2; the primary and secondary winding elements are alternately and closely disposed with the same direction of winding and are connected to one another in parallel, t_1 and t'_1 being the terminals of the primary side and t_2 and t'_2 those of the secondary side.

The following table shows the results obtained by measurements made on a transer in which the primary and secondary winding elements were alternately disposed and the number of the winding elements, connected in parallel in both the primary and secondary sides, was gradually increased; the dimensions of these winding elements was the same as explained in connection with the element shown in Fig. 2.

Number of winding elements	*primary*	2	3	4	5	12
	secondary	2	3	4	5	12
Main inductance (mH)		0.32	0.32	0.32	0.3	0.28
Leakage inductance (mH)		5.2	3.2	2.4	1.6	1.1
Primary resonant frequency due to main inductance (Mc/s)		3.1	2.9	2.8	2.7	2.4

As seen from the table, the leakage inductance decreases as the number of winding elements in the transfer is increased. That is, the electro-magnetic coupling between the primary and secondary sides becomes closer as the number of winding elements is increased.

In this case, it is apparent from the table that the main inductance and the primary resonant frequency are substantially constant. Thus the phase capacitance of the transer is scarcely increased although the distributed capacitance between the primary and secondary winding elements increases as the number of winding elements is increased. Accordingly, such a transer, or a transformer made by combining and connecting these transers, shows smaller dynamic attenuation at higher frequencies since all the transers are constructed so as to have substantially minimum phase capacitance.

Fig. 4 shows a transformer which is made by combining and connecting six transers, T_1—T_6, each of which is similar to that shown in Fig. 3 and each of which has a 1 : 1 transformer ratio.

Terminal t'_1 of the primary winding of the first transer T_1 is connected to terminal t_1 of transer T_2 through conductor 1, whilst the secondary side terminal t'_2 of transer T_1 is connected to terminal t_2 of transer T_2 through conductor 2.

Terminal t_1 of transer T_1 and terminal t'_1 of transer T_6 serve as the primary terminals of the transformer whilst terminal t_2 of transer T_1 and terminal t'_2 of transer T_6 serve as the secondary terminals of the transformer. With this connection, there will be scarcely any phase difference between the voltages appearing across any loop of the primary and the adjacent loop of the secondary winding element of each transer. Therefore, the phase capacitance of this transformer is substantially minimised.

It must be stressed that when interconnecting a plurality of transers, the transers should be connected so as to have a minimum phase capacitance. A suitable form of connection is illustrated in Figure 4.

Fig. 5 and Fig. 6 are respectively plan and side views of the transformer as shown in Fig. 4. It is preferable to minimise the phase capacitance between the opposite sides of adjacent transers (i.e. between T_1 and T_2, T_2 and T_3 etc.) by using, for example, a thin insulating sheet 3 having a thickness of 1.2 mm as a spacer or by providing adequate space between adjacent transers, which at the same time makes it possible adequately to control the electromagnetic coupling between the transers. A sheet of metal can also be used as a spacer.

A core-less transformer can be manufactured by covering the above mentioned transformer surface with suitable insulating paint 4, packing it into a case 5 and packing a stuffing material 6 in the gaps formed therebetween. Such core-less transformers have frequency band widths greater than 10 times those of the usual transformers. Thus transformers according to this invention do not suffer from the faults which result from using the usual iron core transformers, especially in the case of superimposed direct currents and transient phenomena.

Fig. 7 shows the results of measurements illustrating the frequency response characteristics of transformers according to this invention, which are constructed by using winding elements of the type shown in Fig. 2.

The horizontal axis represents the frequency *f* and the vertical axis represents the impedance deviation in decibels, when the load resistance is 2 kilo-ohms.

As seen from the curve *a*, this transformer has a frequency range of about 50 kilocycles/sec. to 6 megacycles/sec. When such a wide frequency range is not required, the number of transers can be reduced. For instance, curve *b* is obtained with two transers and curve *c* is obtained with one transer. On the contrary, a transer according to this invention can cover a wider frequency range down to a very low frequency by using a suitable iron core. For instance, curve *d* is obtained, when a core of 45% permalloy plate of 0.35 mm thickness is used in a transformer consisting of 6 transers. A transformer so constructed can cover a very wide frequency range, i.e., from 80 C/s to 6 MC/s.

Another example of this invention is as follows:—

The primary and secondary windings of this transformer consists respectively of a number of single layer winding elements each of 120 turns of 0.08 mm diameter wire, which are successively interposed between each other as shown in Fig. 3. The transformer is manufactured from 3 transers, each having 40 primary and 40 secondary single layer windings, and these transers are connected in series both in the primary and secondary sides so as to make the transformer ratio 1 : 1; the transformer also has a permalloy core. Accordingly the total number of turns of this transformer is 28800. Experimental results obtained with this transformer show that, the primary and secondary impedances are both 75 ohms; the attenuation deviation is less than 1 db, and the frequency response is substantially flat over a frequency band ranging from about 2 cycles to 10 mega-cycles per second.

In order to obtain a transformer having higher impedance and wider frequency range characteristics, the number of transers connected in series is increased and cores of higher quality are used. Other frequency characteristics can be attained by using different combinations of transers or groups of transers.

If the conducter of a coil is thickened in order to decrease its direct current resistance, the electro-magnetic coupling coefficient of the coil is decreased and the skin effect is increased. The electro-magnetic coupling between the primary and secondary windings may, however be increased and the direct current resistance and the skin effect simultaneously decreased, by increasing the number of winding elements connected in parallel in a transformer according to the present invention.

A transformer having a step-down ratio of 3 : 1 in accordance with this embodiment of the invention, can be made by winding both the primary and secondary windings from wires of substantially the same thickness; the primary winding element being of the type illustrated in Fig. 2 whilst the single layer secondary winding element is wound from three wires wound together in the same plane and connected together in parallel.

Thus the size of the secondary winding element is substantially the same as that of the primary winding element and there is close electromagnetic coupling and minimum phase capacitance between the primary and the secondary windings.

A transformer having a different impedance and a large step-up ratio can be manufactured by interconnecting any desired number of transers, the connection being such that the secondary terminals of each transer are connected to the primary terminals of the following transer.

If a transformer having a large number of windings or a large step-up ratio is required, winding elements of the type shown in Fig. 2 may be used, the desired ratio being obtained by suitably connecting the elements.

For instance, a transformer having any desired ratio can be manufactured by connecting the primary or the secondary winding elements in series or parallel; on the other hand, the secondary windings may be used separately.

A transer according to the present invention can also be tapped at any number of points along its windings.

A transer has been described having winding elements of the basic type shown in Fig. 2 in regular interposition but a transer can also be made in other ways. For instance, a transer having any desired number ($n>1$) of winding elements which are closely coupled together can be manufactured by winding the same number of conductors in their respective planes at the same time. A winding element can be manufactured by winding n conductors in a plane at the same time, the conductors being closely coupled with one another.

Such a winding method can be applied either to winding elements of the type shown in Fig. 2 or to solenoid type winding elements as hereinafter described.

A transformer utilising solenoid type windings can also be manufactured according to the present invention. Fig. 8 shows one example thereof. In Fig. 8, B is a sectional view of a cylindrical bobbin, and X—X′ is the central axis thereof. Eight insulated conductors are wound closely together in the same layer, the winding being advanced from left to right.

The beginnings of four of the eight conductors are terminals t_1 to t_4 inclusive of the primary winding elements e_1 to e_4 inclusive, whilst the beginnings of the other four conductors are terminals t_5 to t_8 inclusive of the secondary winding element e'_1 to e'_4. It is preferably that each group of turns of eight conductors is loosely coupled to the next group of turns.

t'_1 to t'_4 inclusive, are the other terminals of the primary winding elements and t'_5 to t'_8 inclusive, the other terminals of the secondary winding elements. Thus, this single layer on the bobbin may be considered as a transer having four secondary and four primary windings. The eight windings are wound in the same sense and in the same advance direction so that the phase capacitance between respective winding elements becomes very small. A transer can similarly be manufactured by winding many primary and secondary winding elements as a second layer on the first layer over an insulator B′, this insulator serving to decrease the electro-magnetic coupling between the two layers. The number of winding elements can be increased by winding further winding elements on the outside of the second layer of the transer and so on. A plurality of transers, each of which is wound with one layer on a separate bobbin, can be combined and connected in a similar manner to that previously described for the transer of Figure 3.

The above mentioned primary and secondary winding elements and transers are always connected in such a way that the phase capacitance is as small as possible. For instance, the beginning terminals t_1—t_4, inclusive and the corresponding ending terminals t'_1—t'_4 inclusive of the primary winding elements illustrated in Fig. 8 may be respectively connected in parallel, while corresponding terminals of the secondary winding elements can be regularly connected in parallel.

The primary and/or the secondary winding elements can also be connected in series. In this case, the end of one winding element should be successively connected to the beginning of the next winding element.

Both the primary and secondary winding elements of the second layer can similarly be connected in series and/or in parallel.

Transers of the first and the second layer may be connected in series, but it is not desirable to connect the transers of two layers in parallel, since the different layer transers will have different electrical constants owing to the different diameters of their windings.

As described above, in order to minimise the phase capacitance, all the primary and secondary winding elements must be connected in such a way that all the windings have their turns wound in the same sense and in the same advance direction.

Another example of a transformer utilising solenoid-type winding is shown in Fig. 9. In Fig. 9, B is a sectional view of a cylindrical bobbin and x—x′ is the central axis thereof. Five windings e^1, e^2, e^3, e^4 and e^5 are mounted on the bobbin. These windings advance from left to right with the same sense of winding (for example in the clockwise direction) so as to make a closely-coupled regular interposition. The primary side of this transformer consists of the windings e1, e3 and e5 connected in parallel and the secondary side consists of the windings e2 and e4 connected in parallel. This type of construction is particularly suitable for video transformers; in this case, the windings are more closely coupled as the number of windings is increased. The ratio of this transformer is determined by the number of primary and secondary winding elements. In this solenoid type of transformer, desired electrical characteristics can be obtained by mounting a plurality of transers separately on the same bobbin, thereafter connecting the transers in parallel or series according to the characteristic desired.

This invention can also be applied to magnetic amplifiers and the like having primary and secondary windings. This invention can also be applied in the same way to a transformer and the like having more than one primary and one secondary winding. In this case, all windings, which must each comprise at least two winding elements, other than one of the primary windings may be considered at the secondary. The winding elements, the relative arrangement of the winding elements, the mutual connection of the winding elements and the transers and transformers consisting of such winding elements can be made by applying any of the usual techniques well known in the art.

It will be understood that the winding elements can be manufactured from cable composed of a tubular wire and an inner wire which is disposed co-axially within the tubular wire.

WHAT I CLAIM IS:—

1. An electrical transformer which is characterised in that its primary and secondary sides each have at least two single layer winding elements, all said single layer winding elements being disposed to provide alternate primary and secondary windings which are electromagnetically coupled and are in intimate spatial relationship to each other, all said winding elements being wound in the same sense and in the same advance direction, all said single layer winding elements having substantially the same dimension between their extreme terminations, and all said single layer primary winding elements being interconnected in such a manner that the transformer has the minimum phase capacitance as hereinbefore defined.

2. A transformer according to Claim 1, wherein each single layer winding element is a closely wound flat spiral of one or more insulated conductors, all said single layer winding elements having substantially the same radius, all said conductors in each single layer winding element being connected in parallel with each other.

3. A transformer according to Claim 2 wherein each primary single layer winding element is wound from one insulated conductor and each single layer secondary winding element is wound from one insulated conductor, all primary and all secondary winding elements being wound from a conductor of the same diameter; said transformer having a 1 : 1 ratio.

4. A transformer according to Claim 2 wherein each single layer primary winding element is wound from one insulated conductor and each single layer secondary winding element is wound from more than one insulated conductor, all said winding elements being wound from insulated conductors of the same diameter and all said wound conductors in any secondary winding element being connected in parallel with each other, said transformer having a step-down ratio.

5. A transformer according to Claim 2 wherein each single layer primary winding element is wound from more than one insulated conductor and each single layer secondary winding element is wound from one insulated conductor, all said winding elements being wound from insulated conductors of the same diameter and all said windings of any primary winding element being connected in parallel with each other; said transformer having a step-up ratio.

6. A transformer according to Claim 2 wherein each single layer primary winding element is wound from one insulated conductor of diameter "P" and each single layer secondary winding element is wound from one insulated conductor of diameter "S"; said transformer having a step-down ratio if S is greater than p and a step-up ratio if s is less than p.

7. A transformer according to any of Claims 1 to 6 containing more than two single layer winding elements in both its primary and secondary windings, all said primary single layer winding elements being interconnected and some or all of said secondary single layer winding elements being interconnected, said interconnections being made in such a manner so as to obtain the desired transformer characteristics and to minimise the phase capacitance as hereinbefore defined of the transformer.

8. A transformer according to Claim 1 wherein all the winding elements are of the same length and are wound in a single layer helix in the same sense and in the same advance direction, said primary and secondary windings being alternately disposed in the axial direction of the helix, all said primary windings being interconnected and some or all of said secondary windings being interconnected, these interconnections being made in such a manner so as to obtain the desired transformer characteristics and to minimize the phase capacitance as hereinbefore defined of the transformer.

9. A transformer according to Claim 1,

wherein more than one transformer according to Claim 8 are disposed about a common axis, said transformers having different cross-sectional radii, being interconnected and not being closely electro-magnetically coupled together, said interconnections being made in such a manner that all the primary and secondary windings having one cross-sectional radius are connected in series with the primary and secondary windings respectively corresponding to one or more other cross-sectional radii.

10. A transformer according to Claim 1, wherein each single layer winding element is a closely wound helical coil of an insulated conductor, all said primary and secondary helical coils being radially disposed about a common former and having the same length along the former, all said primary single layer winding elements being interconnected and some or all of said secondary single layer winding elements being interconnected; these interconnections being made in such a manner so as to obtain the desired transformer characteristics and to minimize the phase capacitance as hereinbefore defined of the transformer.

11. A transformer according to any of Claims 1 to 10 wherein the secondary and primary winding elements are wound about an iron core.

12. An electric transformer comprising more than one transformer according to any of Claims 1 to 10 interconnected in such a manner so as to obtain the desired transformer characteristics and to minimize the phase capacitance as hereinbefore defined of the transformer.

13. A transformer according to Claim 12, wherein the interconnected transformers are electro-magnetically screened from each other.

14. A transformer according to any of Claims 1 to 13 substantially as hereinbefore described with reference to Figures 2 to 9 of the accompanying drawings.

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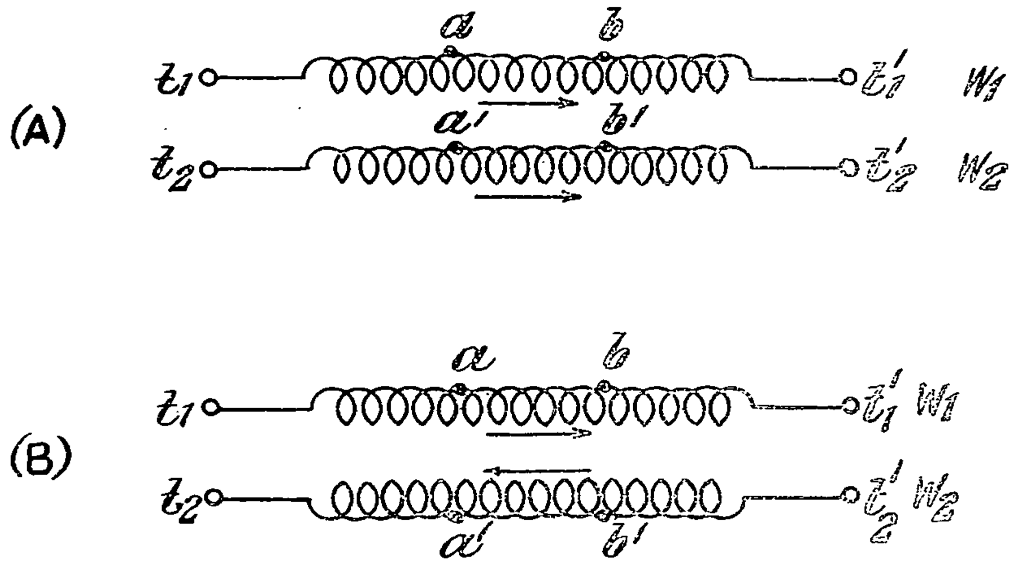
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Fig. 1

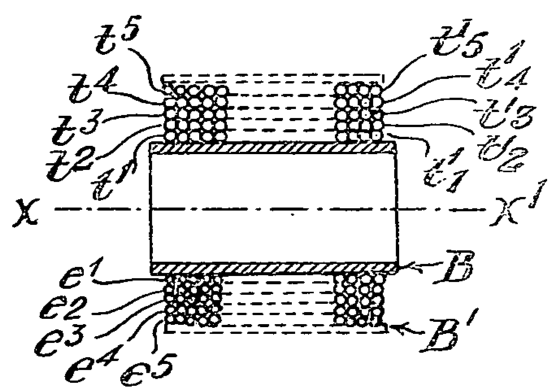
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Fig. 9

Fig. 2

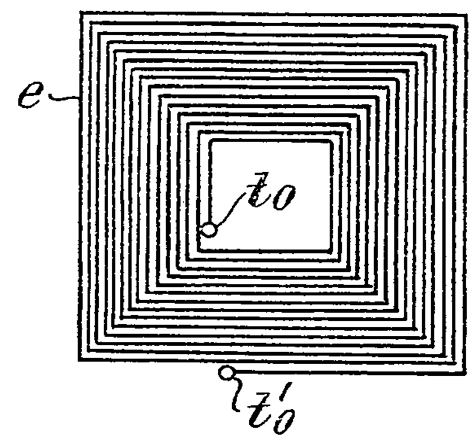


Fig. 5

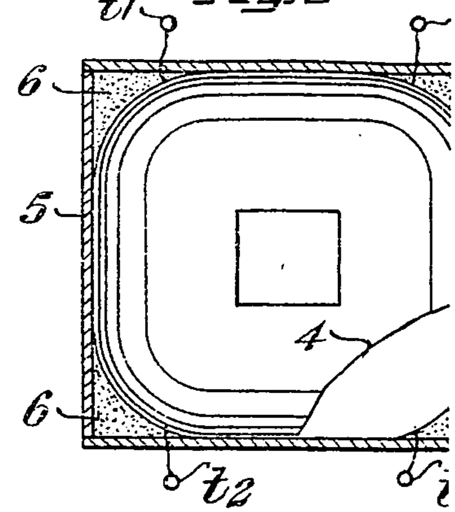
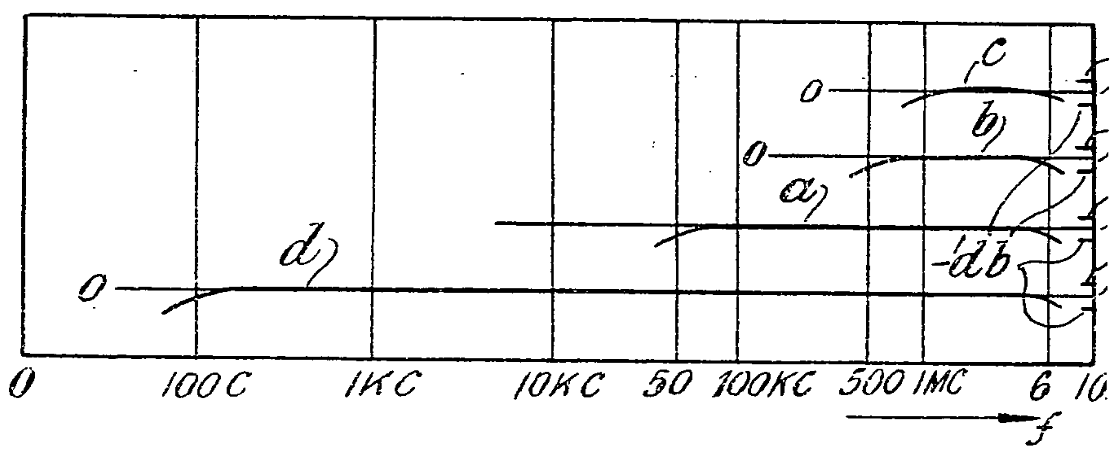
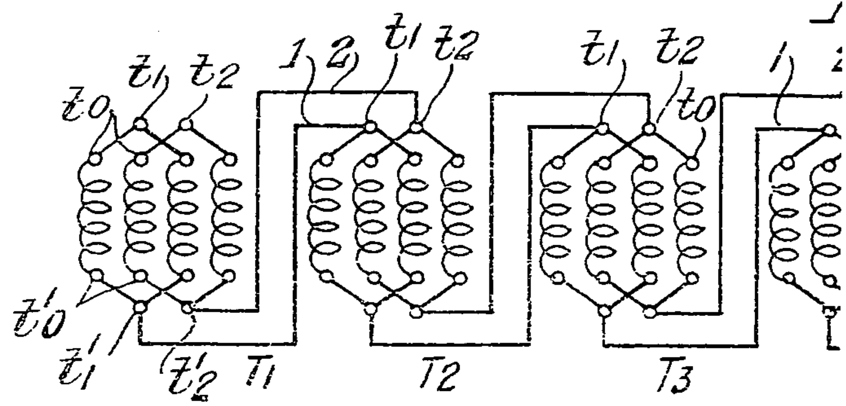


Fig. 7





827,600 COMPLETE SPECIFICATION
2 SHEETS
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SHEET 2

Fig. 5

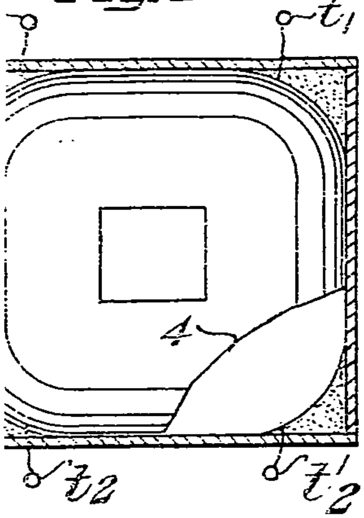


Fig. 6

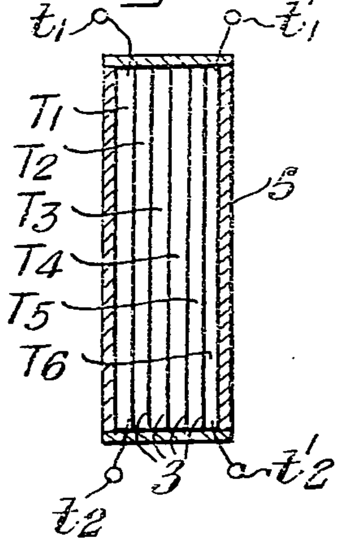
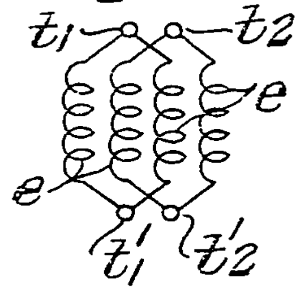


Fig. 3



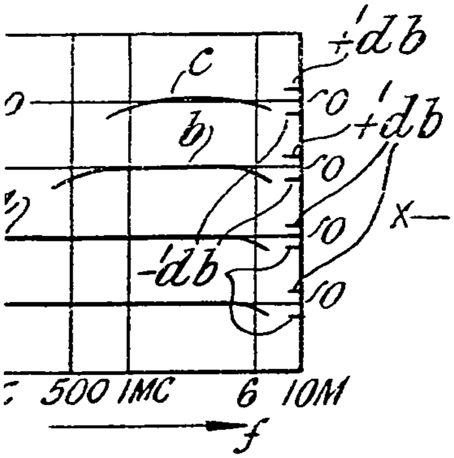


Fig. 8

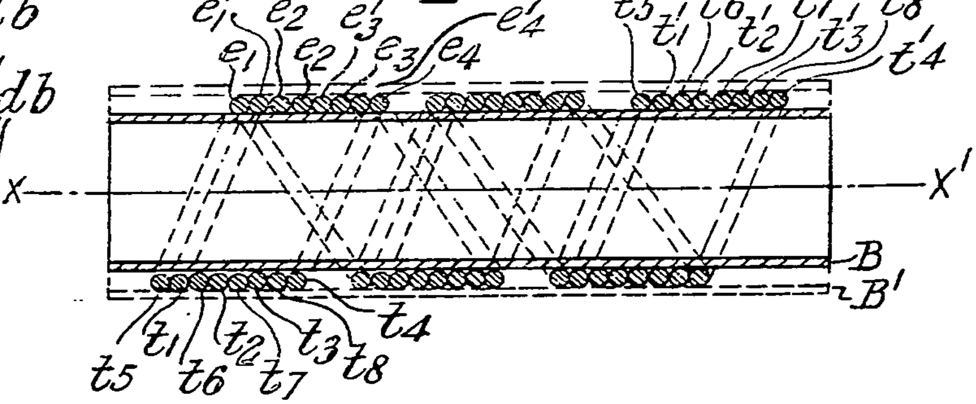
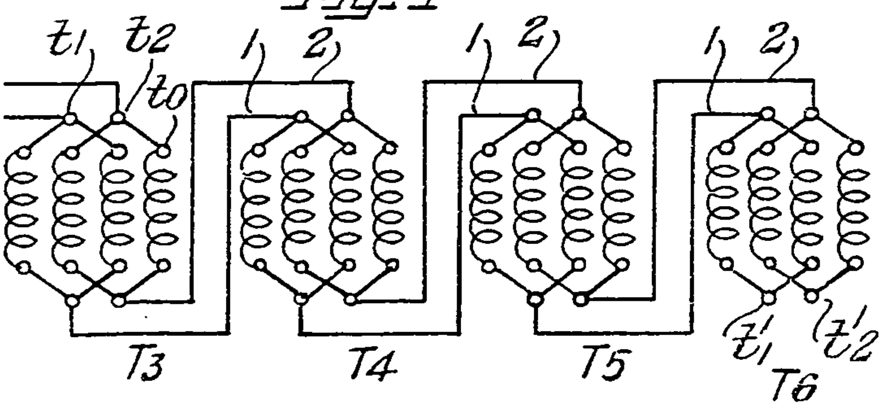


Fig. 9



827,600 COMPLETE SPECIFICATION

2 SHEETS

This drawing is a reproduction of the Original on a reduced scale.

SHEET 2

Fig. 2

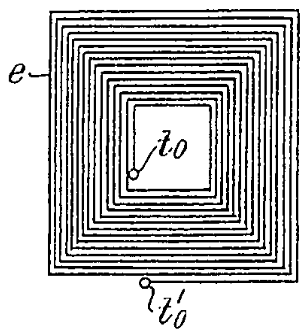


Fig. 5

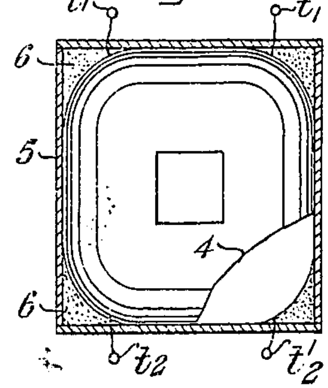


Fig. 6

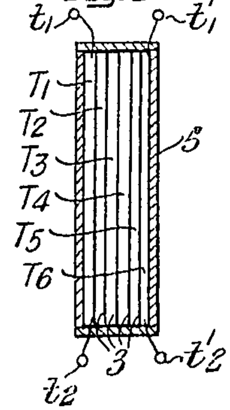


Fig. 3

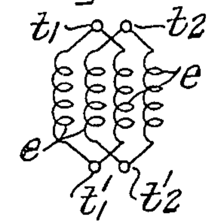


Fig. 7

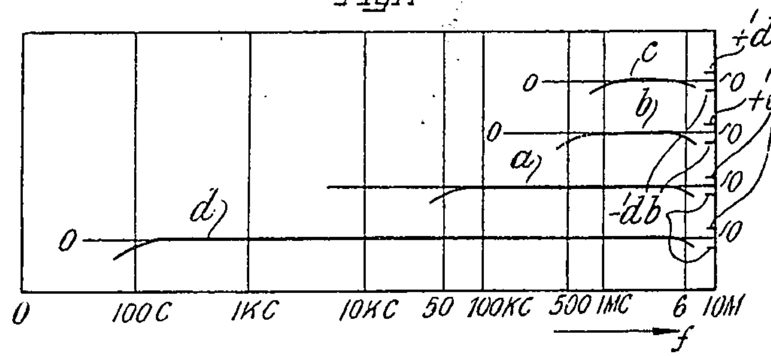


Fig. 8

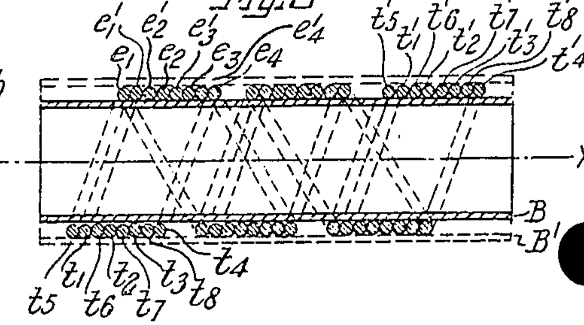


Fig. 4